Paper

Analysis of Impression of Robot Bodily Expression

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A set of physical feature values is proposed in order to explain impression produced by bodily expression. The concept of designing the value set is based on Laban Movement Analysis which is a famous theory in body move-ment psychology. Impressions produced by body expression are closely related to these feature values. Each of the feature values is defined mathematically, so that it is easy to implement in a computer. Also the feature values are calculated on general body movements. Therefore, the set can be implemented in body expression systems of robots and computer graphics bodies in order to facilitate quantitative evaluation and forecast of impression produced by their bodies. This paper describes the concept and an example of implementation on a robot. Validity of the set is verified in an experiment.

Keywords: bodily expression, quantitative evaluation of impression, laban lvlovement analysis, dancing robot, nonverbal communication.

1. Introduction

In the entertainment field, attempts are being made to apply body movement by robotic engineering or by computer graphics to bodily human expression.

We studied expression produced by body movement so, using body movement properly, they can be made to interact with humans. In other words, it is essential for body movement itself to accurately evaluate impressions produced on audiences, to produce own movements autonomously, and to transmit impressions to be expressed to the audience properly based on the context.

We consider impressions produced by body movement can be clarified by a set of substantive quantities that represent the features of movements (physical features). Speed is one of typical physical features. High-speed actions catch attention of the audience strongly, and produce psychological impressions. It is therefore important to systematically compose a set of physical features, to which the audience will first pay attention, when impressions of bodily expression are to be evaluated.

A set of physical features is required for satisfying conditions such as (a) sufficiently correlation with impressions, (b) provided with all dynamic and geometrical features in movements that can readily be applied to general movements of a human body, (c) mathematically rational so control of body movement can itself evaluate impressions produced by movements, and (d) provided with knowledge of expression science. This paper proposes sets of physical features that satisfy these conditions.

Some prominent studies related to this paper are as follows:

(1) Studies by Ikeura et al.[9], by Shibata et al.,[12] and by Mizogushi et al.[16] are devoted to the analysis of the correlation between physical features of partial behavior and the resulting impressions. They are concerned about factors of movement such as velocity distribution, acceleration, and robot-to-human approaches of industrial robots used in close human proximity to analyze the correlation between physical features and impressions subjectively received by humans.

(2) With the use of animal robots, studies have been conducted to analyze the correlation between physical features of general body movement and resulting impressions. Iguchi et al.[15] have developed an automatic doll, proposing 3 items for subjective evaluation of its performance, i.e., "warmth," "tenderness," and "conspicuousness." Ikeura et al.[10] reported the correlation between degrees of freedom of human body movement and powers of subjective appreciation by the audience of dancing. Hattori et al.[3] physically compared the behavior of Bunraku puppets accompanied by emotional expression and those accompanied by no emotional expression. Mizoguchi et al.[5] reported a correlation between conditions of an animal robot (e.g., robot-to-human gaze and robot-to-human distance) and subjective human-to-robot impressions by humans about "whether the robot pays attention to a human."

In these studies, however, physical features of movements have been established based on specific questions. In other words, these studies has hardly succeeded in proposing effective physical features closely correlated with impressions of general bodily expression.

Our objective is to set up sets of physical features based on Laban Movement Theory substantially contributing to the progress of dance theory, to propose quantitative evaluation for impressions produced in widely observed general behavior, and to verify the validity of the method in an experiment.

2. Bodily Expression of Movement and Laban Features

2.1. Bodily Expression of Subjects of Our Study

Generally, expression is composed with a complex of elements. Since our purpose is to find and analyze expressional elements contained in body movements, the scope of this paper should be limited within bodily expressions as follows:

1) Unilateral expression.
Audiences are supposed to see a body movement simply as onlookers without interaction. Expressions inconsistent with the audience's attitude, e.g., making contact with or turning gaze upon body movement, is excluded.

2) Expressions of basic emotions.
Expressions of basic emotions (joy, anger, grief, pleasure) of body movement is examined.

3) Bodily expression alone.
No sound used.

4) Exclusive of ritual expression.
Ritual or bodily expression related to recognition, such as "salutes," varied based on manners, customs, or cultures so ritual expression is excluded from our study.

5) Not under contextual conditions.
No context is provided specifically for expressions. In other words, no reason for a dance or cues signaling the start of dancing are shown to the audience. Attention is given only to audience impressions of basic emotions from the bodily expression of movement. Subjective judgment by the audience about the meaning or value of movement is excluded from our study.

2.2. Theory on Correlation between Psychological Conditions and Body Movement

Charles Darwin[2] is the first one who got the idea of rearranging movement with multiple degrees of freedom (DOF) into a set of quantities that represent dynamic and geometric features with lesser DOF. Based on Darwin, expressions produced by body movement can structurally be classified into 2 types: fighting and submission. Expressions of fighting are characterized by features similar to those of threatening movement in actual fighting. Such expressions are displayed by a fighter to an opponent with a fist clenched and the arm lifted in a straight line. Fighting suggests movement in fighting and gives the audience an impression of anger or determination.

Expressions of submission are characterized by features displayed to an opponent in retreat or surrender. Submission can be used to reverse features of fighting. For example, submission with the fist loosened and the arm slowly lowered in a curved line suggests a sense of relief instead of a sense of hostility.

Table 1. Dynamic and geometrical features of effort elements.

Effort	Indulging form	Fighting form
Weight	Light	Strong
Space	Indirect	Direct
Time	Sustained	Sudden

2.3. Laban Features and Mathematical Formulation

In dance, systems used for detailing the dynamic and geometrical features of body movement are called as the movement systems,[14] the Laban system excels in comprehensiveness, explicitness, and mathematical preciseness for conceptual use.

Our objective is to mathematically define and quantify dynamical geometrical features used in the Laban system in body movement. Below, resulting quantities are called "Laban features."

In this section, we limit ourselves to a general explanation and technological interpretation of Laban features. For more concrete formulation, a detailed description will be given in Section 2.4, while the generality and the uniqueness of formulation are examined in Section 2.5.

To improve the movement system, Laban divides Darwinian items, yielding the Laban system. The Laban system has changed and advanced with time. That applicable here is a revised version based on the newest Bartennieff[1] and referencing Kestenberg.[4].

Based on Laban, items are structurally classified into fighting and indulgence. Fighting is active, prominent, brisk body movement, while indulgence is unsteady body movement usually observed in intoxicated persons. The Laban system presents features for fighting and indulgence roughly classified into Effort and Shape. Effort represents dynamic features of movement or the quality of movement. Shape represents geometrical features in overall body shape. The 3 elements of shape are as follows (**Table 1**):

Weight Effort: Weight effort stands for vigorousness of body movement. When body movement is indicated as strong, it is in a state of fighting; when it is indicated to be light, it is in a state of indulgence. Assuming that vigorousness is taken as a physical quantity, it is considered to correspond to the amount of energy per unit time put into the implementation of body movement. For the mass of the moving part, the mass of body movement foreseen by appearance (visual mass) is estimated and used. There are different views from the above: for example, the top speed and momentum during movement can be taken as vigorousness. Acceptable interpretation are discussed in Section 2.5.

Space Effort: Space effort stands for the degrees of directional deflection in body movement. Fighting is characterized by the convergence of arms and gaze in a certain direction (Direct), while indulgence is characterized by disagreement between moving or spreading directions of limbs and lines of gaze (Indirect). We unify

Table 2. Two dimensional shape.

Plane of Movement	*Table Plane*	*Door Plane*	*Wheel Plane*
Fighiting Form	Enclosing	Ascending	Retreating
Indulging Form	Spreading	Descending	Advancing

spreading directions of limbs and lines of gaze of body movement. For example, the inner product of the unit direction vector can be used for numerical calculation.

Time Effort: Time effort stands for hurriedness in changes of movement. Fighting is characterized by bursting movement (Sudden), while indulgence is characterized by continuing movement (Sustain). From the point of view of robot control, hurriedness is taken as a software load (in the case of humans, a cognitive load). The number of commands for movement per unit time can be used as the value of time effort. The method described above is applied to the definition of actual robots given in sections that follow. The above number of commands can be used as changes in movement with time. In other words, the change of speed (or acceleration or momentum) in each part of body movement per unit time can be used for numerical calculation.

Shape or geometrical features of overall body movement is described below. **Table 2** lists the 3 elements of shape. Shape can be defined in several ways. In this paper, a "2-d Shape," which references Kestenberg characterized by a clear definition, is adopted.

Assuming that horizontal, front, and lateral planes of silhouettes of body movement are virtually projected, 2-d shape can be defined as the spread and movement of each silhouette. The layout of the front and lateral planes is determined based on the trunk (the pelvis) of body movement. **Table 2** lists conceptual diagrams of each plane and spreading.

The simplest mathematical interpretation of "the spread of silhouettes" is an inner area of the convex hulls of each silhouette and the movement is taken as a centroidal shift of the silhouette. For some concrete examples below, however, the shape of convex hulls is not stated specifically for the simplification of calculation. Instead, the angle of each joint of body movement is directly made use of, so shape can be defined more simply.

Door Plane Shape: Door plane shape represents the spread of each silhouette on the front. The region (or, the center of gravity) of the silhouette leaned in the upper direction suggests fighting; leaned in the opposite direction, it suggests indulgence.

Wheel Plane Shape: Wheel plane shape represents a lengthwise shift of the silhouette on the lateral plane. The region (or, the center of gravity) of the silhouette caused to retreat suggests fighting; when caused to advance, it suggests indulgence.

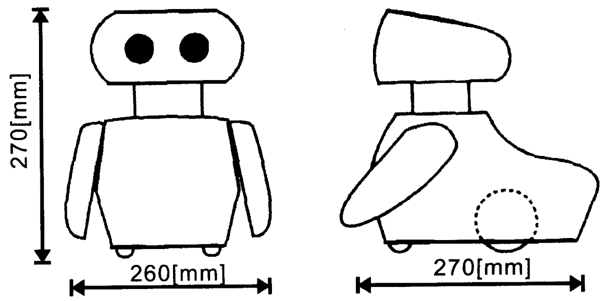
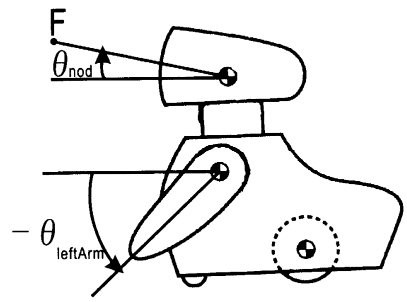


Fig. 1. Experimental dancing robot.



$$v_{turn} = \dot{\theta}_{leftWheel} - \dot{\theta}_{rightWheel}$$

$$v_{translate} = \dot{\theta}_{leftWheel} + \dot{\theta}_{rightWheel}$$

Fig. 2. Definition of joint angles and velocities.

Table Plane Shape: Table plane shape represents the spread of the silhouette on the horizontal plane. For a body movement with arms in particular, it is important to bring the end of each arm close to the line of gaze and, accordingly, it is proper in many cases to regard the terminal points as the spread of convex hulls. A relatively narrow spread suggests fighting; a relatively wide spread (where the limbs spread randomly), indulgence.

In general, the 6 elements of Laban features are independent from each other. The motion for a human to push a heavy object requires a large quantity of energy, so weight effort is in a state of fighting. Changes in movement with time are small, so time effort is in a state of indulgence. With regard to elements of the Labon features, therefore, both fighting and indulgence are liable to exist together.

2.4. Definition of Laban Features with a Robot

A concrete definition of Laban features in connection with the body mechanism of a robot is given as follows:

The robot used here (dancing robot) is shown in **Fig.1** General view], in **Fig.2** [Definition of joint angles and velocities], and in **Fig.5** [Pictures in process of dancing].

As shown in **Fig.2**, the moving parts of the dancing robot are provided with 1 DOF for rotation of both arms and 1 DOF for the nodding motion of the head. In addition, the robot is provided with 2 wheels at its bottom so it can move on the floor.

Efforts and shapes are defined as follows for making values larger in fighting.

1) Weight Effort is taken to be the total sum of the Kinetic energy at each moving part under weight per unit time. It can be formulated into Eq.(1) as joint angles and velocities in square-progression.

$$WeightEffort = A\,(a_{la}\dot{\theta}^2_{leftArm} + a_{ra}\dot{\theta}^2_{rightArm}\ a_{tr}v^2_{trans}\ .$$

$$+ a_{tn}v^2_{turn} + a_{tn}v^2_{turn} + a_{nod}v^2_{nod})\ \ldots\ldots\ldots \quad (1)$$

The weights noted as "a" in Eq.(1) should be adjusted with respect to the visual mass and conspicuousness of each part. The item corresponding to the movement of the trunk is made relatively larger $a_{tr} = 4$, $a_{tn} = 4$ and relatively smaller for the item corresponding to the movement of light-weight parts, such as the arms and the neck $a_{la} = 2$, $a_{ra} = 2$, and $a_{nod} = 1$. The coefficient A that is related to the whole is supposed, in an aesthetic sense, to relax the amount of alienation from the number of digits of the other Laban features. A is taken to be 0.001. "A" in this case has no practical influence on the results of the analysis below.

2) Space Effort is taken to be the total sum of the directional differences under weight between the angles of elevation of both arms and the nodding angles of the head. It can be defined by Eq.(2).

$$SpaceEffort = b_{tn}|\,\theta_{turn}| + b_{lr}\,|\theta_{leftArm} - \theta_{rightArm}|$$

$$+ b_{nl}|\theta_{leftArm} - \theta_{nod}\ | + b_{rn}|\,\theta_{rightArm} - \theta_{nod}\ |\ \ .\ . \quad (2)$$

In setting up weight b, the weight of the term b_{lr} (or the agreement between the directions of both arms which creates a deep impression about the bilateral symmetry of movement) and the weight of the term b_{tn} for the turn are taken to be –5. The terms b_{nl} and b_{rn} for the agreement between the nodding angles and the angles of both arms are taken to be –1, provided conspicuousness is weak. To make adjustment to positive and negative directions, the coefficient is taken to be negative.

3) Time Effort is taken to be the number of commands issued per unit time to change the target value with regard to joint angles of the dancing robot. For this dancing robot system, dancing commands are described with the use of musical scores and analogies for convenience of the compilation of dancing movements.[6)] One command is called "note." When the time-axis is subjected to the process of quantization, the unit length obtained is called "beat." Equation (3) below is obtained by formulating the definition of time effort with notes and beats.

$$TimeEffort = \frac{(Number\ of\ Notes\ in\ one\ Beat\ )}{(Time\ span\ of\ one\ Beat\ )} \quad (3)$$

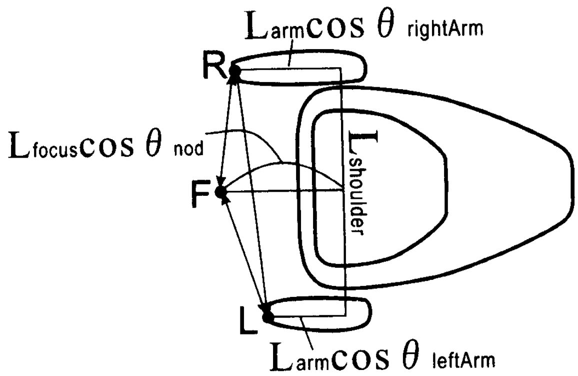


Fig. 3. Conceptual diagram of Table-Plane.

I) Door plane shape is defined as the total sum of the sine under weight for the angles of elevation of both arms and the head as shown in Eq.(4).

$$DoorPlane = c_l\sin\theta_{leftArm} + c_r\sin\theta_{rightArm} + c_n\sin\theta_{nod}\ \ldots\ldots\ldots\ldots \quad (4)$$

The sine is used to represent the degree of the upward look of each joint angle. It is considered proper to equalize the weight of each term, so $c_l = c_r = c_n = 1$.

II) Wheel Plane Shape is defined as the total sum of the advancing-retreating velocities of the robot and the lengthwise velocities at the ends of both arms under weight as shown in Eq. (5).

$$WheelPlane = d_t\,v_{translate} + d_lL_{arm}\frac{d}{dt}\cos\theta_{leftArm}$$

$$+ d_rL_{arm}\frac{d}{dt}\cos\theta_{rightArm}\ \ldots\ldots\ldots \quad (5)$$

L_{arm} represents the length of the arms of the dancing robot, for which 10cm is to be substituted. The weight is estimated as follows based on the visual mass at the moving parts, i.e., the weight of the trunk dt = -6, the weight of the arm ends $d_l = d_r = -1$.

III) Table plane shape is defined based on **Fig.3**. The points L and R each stand for the terminal points of both arms projected on the horizontal plane. For the definition of the line of gaze, a point 10cm before the eyes (= L_{Focus}) of the robot is chosen, and it is taken as F when projected on the horizontal plane. For Table Plane Shape, the mutual distances between the points L,R, and F are calculated based on Eq.(6) to (8). "L_{shldr}" represents the shoulder breadth of the dancing robot, for which 15.4cm is to be substituted.

$$T_{lr} = \sqrt{L^2_{shldr} + (L_{Arm}\cos\theta_{lArm} - L_{Arm}\cos\theta_{rArm})^2}\ \ldots\ldots \quad (6),$$

$$T_{nl} = \sqrt{\left(\frac{L_{shldr}}{2}\right)^2 + (L_{Arm}\cos\theta_{lArm} - L_{Focus}\cos\theta_{nod})^2} \quad \cdot \cdot \ (7),$$

$$T_{nr} = \sqrt{\left(\frac{L_{shldr}}{2}\right)^2 + (L_{Arm}\cos\theta_{rArm} - L_{Focus}\cos\theta_{nod})^2} \quad \cdot \cdot \ (8)$$

With the reciprocal of the total sum of the mutual distances, Table Plane Shape is then defined based on Eq.(9) to make adjustment to positive and negative directions.

$$TablePlane = E/(T_{lr} + T_{nl} + T_{nr}) \ . \ . \ . \ . \ . \ . \ . (9)$$

"E" is the coefficient used to make adjustment to the number of digits, which is taken to be 100.

2.5. Discussion on Subjectivity of Definitions

For the definitions of numerical expressions for Laban features described above, definition-framing persons are liable to be confronted with a large number of items that are to be determined at their own subjective discretion. Consequently, certain differences in the results of the definitions are apt to arise among the definition-framing persons. Such differences can be classified into the following 3 types. The tolerances for each type of differences and the measures to deal with them are described below.

1) Differences in definitions in body movement:

Body movement with different mechanisms often have different moving parts, so they are apt to vary in definition-framing. As for shape, differences in mechanisms can be settled if the definitions are framed based on convex hulls of silhouettes of body movement. On condition that effort is defined as the total sum of certain physical quantities under weight, an equation that is useful for calculating a conceptually equalized quantity corresponding to a certain substance is obtained. Superficially, however, different numerical expressions are to be introduced. It is true that a basic problem still remains to be solved, i.e., the conceptual definitions of the "arms" and "front view" of body movement vary with definition-framing persons. For the animal-shaped body movement, however, it is considered that the conflict between the conceptual definitions and the definition-framing persons is insignificant.

2) Differences in definitions in selection of physical quantities: Instead of kinetic energy, for example, the top speed of movement for a related physical quantity may be used, but it is difficult to say which of these is more suitable as a useful element in the process of impression production without any impression investigation experiment. In an actual quantity evaluation, however, physical quantities are in many cases selected based on the experience and knowledge of definition-framing persons. It can be said that a certain definition is successfully framed when physical quantities increase or decrease in plain proportion to the degrees of fighting/indulgence and when the presence of proper correlation with impressions is verified through an extra impression investigation experiment. A method is available for eliminating the subjective view of definition-framing persons and keeping the applied physical quantity constant. From a practical viewpoint, however, it is recommendable to adopt a method that has a closer correlation with impressions or that can be implemented on a simple calculation.

3) Differences in evaluation of the effect on audience:

Some difference exists in impression producing effect between the part that attracts keen attention of audience and the part that attracts small or no attention of audience. Primarily, a CG body movement has no mass and is not always equal in length and in visual effect to an actual body movement. When the CG body movement is required to give a concrete form to the total sum of Laban features by its whole system, therefore, it will have to pass through the process of weighting in consideration of the effect on audience. In practical application, an equation is to be established for framing a definition on the assumption that there is no difference between the 2 parts. Adjustment will then be given empirically to the coefficient so as to take the difference between the 2 parts into a practical consideration. For the evaluation of the coefficient adjustment, an impression investigation experiment similar to what is described in 2) above will be conducted so as to check the intensity of the correlation with the actual impression.

3. Experiments for Evaluating Impressions of Robot Dance

3.1. Hypothesis for Experiments

The following hypothesis is to be verified: "the structure of the process, in which body movement of body movement leaves an impression about basic emotions on audience, can be quantitatively analyzed and described."

3.2. Equipment

Body movement used for the experiments is the robot shown in **Fig.1**. The DOF provided for this robot is shown in **Fig.2**. This robot can move on the floor with the 2 wheels provided at its bottom. One DOF either for the rotation of both arms or for the nodding motion of the head can be controlled by a stepping motor.

The data description formula for dancing movement and the algorithm for movement control are as in Nakata[6].

3.3. Experiment Procedures

1) Let each subject have a questionnaire shown in **Fig.4** and tell him how to fill it, or tell him to single out one from the following four basic types of emotions, i.e., Joy, Surprised, Sad, and Angry. When there is no perti-

* As for impressions of the 1st movements of the robot, mark one of the items listed below with a circle.

Impression: Joy / Surprised / Sad / Angry / Impertinent

Degree: 0 / 1 / 2 / 3 [0 for Impertinent / 1 for Slight / 2 for Medium / 3 for Strong]

* As for impressions of the 2nd movements of the robot, mark one of the items listed below with a circle. (The same applies correspondingly to the following.)

Fig. 4. Questionnaire .

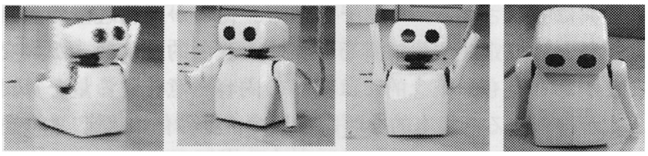


Fig. 5. Typical postures of experimental dancing.

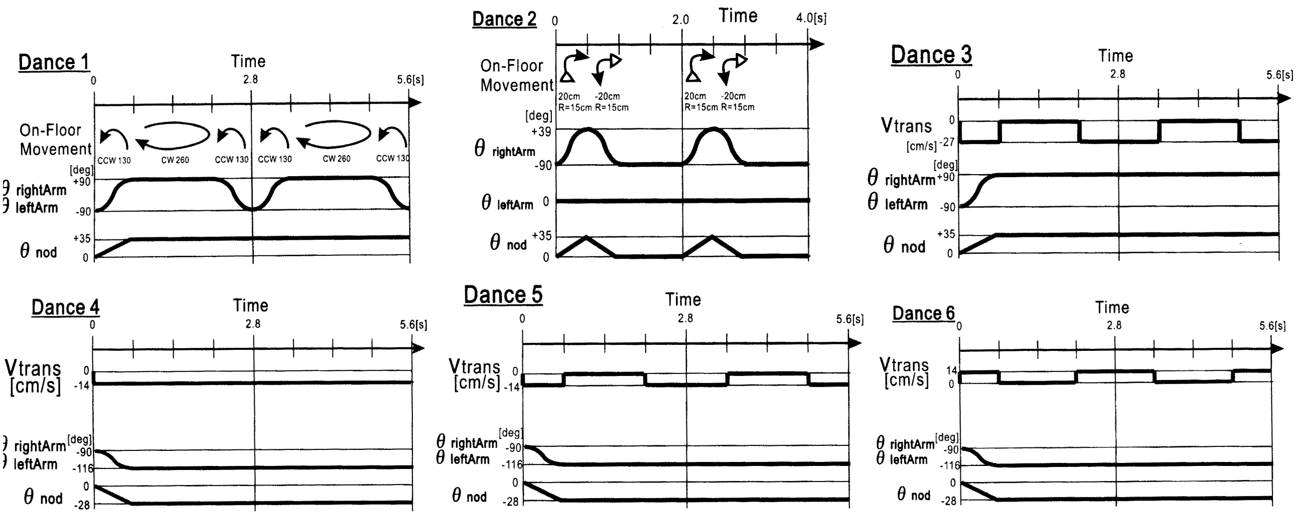


Fig. 6. Movement data of experimental.

nent item to him, he is supposed to select "Impertinent." He is then supposed to single out one from 3 stages of the degrees of impressions, i.e., Slight, Medium and Strong.

2) The robot demonstrates the dances on the floor about 1m in front of the subject. **Fig.5** shows the pictures of the typical postures of the dances performed in the experiment. **Figure 6** shows the movement data on each dance.

Dance 1: The robot repeats a set of rotating motions left and right alternatively on the floor while raising its arms right overhead and turning its head-nodding angle upward.

Dance 2: The robot quickly advances to the right obliquely and quickly returns to the original position. Based on the advancing movement, the robot raises its right arm forward and turns the head-nodding angle upward. The cycle of Dance 2 completes in a shorter time than that of any other dance.

Dance 3: The robot repeats a set of retreating and stopping motions intermittently while raising its arms right overhead and turning its head-nodding angle upward.

Dance 4: The robot retreats continually at a uniform velocity while restoring its arms backward obliquely and turning its head-nodding angle downward.

Dance 5: The robot repeats a set of retreating and stopping motions intermittently while keeping the same posture as that of Dance 4.

Dance 6: The robot repeats a set of advancing and stopping motions intermittently while keeping the same posture as that of Dance 4.

Table 3 lists the numerical values of Efforts and Shapes obtained by using the equations quoted in Section 2.

Values of Weight Effort in Dance 1 exceeds those in other Dances by a great deal. The reason for this is the robot in Dance 1 rotates all the time with a larger turning-radius.

3.4. Results

Subjects consist of 21 engineering university students (17 men and 4 women).

Table 3 lists the results obtained by questionnaires based on 2 types of statistical representations. First, the degrees of impressions are classified into 3 types of Slight, Medium and Strong, which are each represented by "1," "2," and "3," and the responses of all subjects are summed up. This type of totalization is useful for clarifying not only the substances of emotions but also the intensity of expressions. Strictly speaking, however, the numerical values of intensity may not have quality of rational score. Consequently, the data on intensity are disregarded, while the data on the total number of sub-

Table 3. Relationship between Laban's movemental feature values and produced impression.

Dance	Effort			Shape			Impression (score total)				Impression (number of person)				
	weight	*Space*	*Time*	*Door*	*Wheel*	*Table*	Joy	Surprised	Sad	Angry	Joy	Surprised	Sad	Angry	No expression
1	3227	-7060	18.6	20.6	0	0.376	49	6	0	2	17	3	0	1	0
2	451	-3628	40.0	-11.6	34	0.364	1	2	0	10	1	1	0	7	12
3	427	-1060	18.6	20.6	456	0.376	0	30	0	0	0	15	0	0	6
4	201	-1583	7.1	-18.2	465	0.320	0	0	39	0	0	0	20	0	1
5	101	-1583	18.6	-18.2	237	0.320	0	0	29	1	0	0	17	1	3
6	101	-1583	18.6	-18.2	-219	0.320	0	0	21	9	0	0	12	8	1

Table 4. Kendall's correlation coefficient between Laban's Movement feature values and produced impression.

	Effort			*Shape*		
	Weight	*Space*	*Time*	*Door*	*Wheel*	*Table*
Joy	0.93* *Strong*	-0.56	0.18	0.67	-0.07	0.67
Surprised	0.69* *Strong*	-0.15	0.09	0.89* *Ascending*	0.14	0.89* *Enclosing*
Sad	-0.75 *Weak*	0.33	-0.67	-0.61	0.15	-0.61
Angry	-0.15	-0.42	0.67	-0.17	-0.75 *Advancing*	-0.17

(*: $p<0.05$)

Table 5. Factor analysis result on experimental results.

Factor			F1	F2	F3
Factor Contribution			0.33	0.33	0.27
Factor Loading for Inputs	*Effort*	*Weight*	0.98	0.20	-0.08
		Space	-0.94	-0.10	-0.21
		Time	-0.02	0.37	0.84
	Shape	*Door*	0.52	0.79	-0.28
		Table	0.44	0.88	0.12
		Wheel	-0.38	0.27	-0.71
Factor Loading for Outputs	Joy	Score	1.00	0.10	-0.10
		# of Prsn	1.00	0.11	-0.06
	Surprised	Score	-0.14	0.88	-0.35
		# of Prsn	-0.14	0.88	-0.35
	Sad	Score	-0.39	-0.83	-0.41
		# of Prsn	-0.39	-0.84	-0.39
	Angry	Score	-0.06	-0.12	0.98
		# of Prsn	-0.12	-0.20	0.91
Factor Score	Dance 1		2.33	0.44	0.15
	Dance 2		-0.26	0.37	1.49
	Dance 3		-0.63	1.82	-0.69
	Dance 4		-0.41	-1.08	-1.52
	Dance 5		-0.62	-0.66	-0.44
	Dance 6		-0.18	-0.88	0.83

jects responding only to the substances of emotions have preferentially been adopted for analysis. The latter data are shown on the right side of **Table 3**.

The aim of analyzing the experimental results is, as shown in **Table 3,** to clarify the correlation between Laban features (as the stimuli to a human) and the evaluation of impressions (as the responses from a human). The numerical values of these data serve as substantial rank standards with regard to the extent and rank of values, but they are not necessarily provided with the properties of rational score. Consequently, Kendall's rank correlation coefficient is calculated and its validity is verified for the analysis of the correlations.[7]

Table 4 shows the results of the correlation analysis. The number of pairs, in which a significant correlation between each Laban feature value and each impression exists, is 6. They are described as follows:

Correlation 1: A Strong body movement (Weight Effort is provided with Strong feature) is apt to leave an impression of Joy.

Correlation 2: A Strong body movement, in which both arms and the line of gaze are directed upward (Door Plane Shape – Ascending) and the arms and the line of gaze are arranged in one direction (Table Plane Shape – Narrow), is apt to leave an impression of Surprised.

Correlation 3: A Weak body movement (Weight Effort – Light) is apt to leave an impression of Sad.

Correlation 4: An Advancing body movement (Both wheels – Advancing) is apt to leave an impression of Angry.

The analysis of such simple correlations as described above is not sufficient for analyzing the structure of impressions that are formed of a number of Laban features. It seems necessary to increase the number of sets of significant correlations.

A method of factor analysis is recognized as excellent for analyzing the causation between elements. In this paper, therefore, factor analysis is adopted for a quantitative analysis and description of the causation between Laban features and impressions. In other words, the factor analysis will be used for establishing a model for an impression production process and for verifying the hypothesis experimentally built up.

Based on the results of an exploratory factor analysis

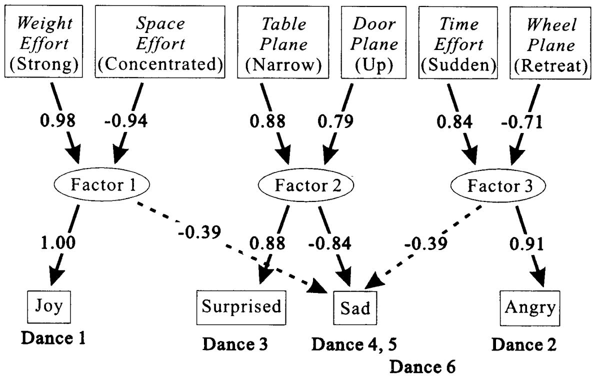


Fig. 7. Path diagram depicting factor analysis result.

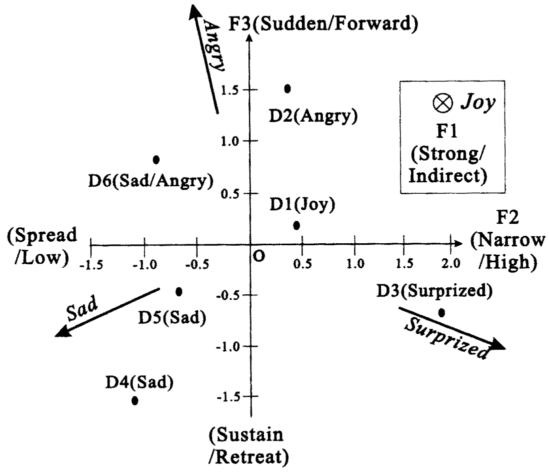


Fig. 8. Spacial representation of similarity of the impressions.

for determining the number of factors, there are 3 factors whose characteristic value is larger than 1. Conventional standard for verifying the validity of factors specifies that the characteristic value is more than 1. In the confirmatory factor analysis, therefore, a model with 3 factors is used for analysis. For estimation of a common feature, SMC is used. For factor orthogonalization, *varimax rotation* is used. The total contribution of 3 factors is 93%. **Table 5** lists the numerical data on the results of the confirmatory factor analysis.

Figure 7 shows the path diagram depicting the structure of the causation that corresponds to the results of the factor analysis. The arrows in the figure stand for the causation, and the digits over the arrows stand for the factor loading. When the absolute value of the factor loading is 0.7 or above, this means that there are close causation there. The arrows shown by solid line are used to indicate close causation. Each of the 3 factors has a certain amount of effects on the intensity of the impression Sad, so weak causation with a factor loading of –0.39 are also shown for reference by the arrows of dotted line.

This path diagram indicates the structure of the mapping as to the distribution of the responses in the impression evaluation based on Laban features of experimental body movement. For example, the diagram can be read as follows: For body movement, in which both arms and the nodding posture are turned upward, the feature value of Door Plane Shape is calculated positively to become relatively larger based on the definition in Section2 ("Up" shown in the diagram represents the positive direction of the numerical value). As this numerical value is correlated to Factor 2 through a loading of 0.79, Factor 2 is influenced to become larger, too. The causation between Factor 2 and the data on the number of responses in impressions is also shown with arrows and loading.

Here, the similarity in Impression Space of each Dance is illustrated with 3-d factor score data. Factor1 in Dance 1 exceeds the other Factors, so Factor 1 is omitted, and 2-d data is plotted in **Fig.8** with the scores related to Factor 2 as the abscissa and with the scores related to Factor 3 as the coordinate. The factor loading on each type of emotions is shown as a directional component of vector in the direction of the emotion. The axis of Factor 1 is perpendicular to the surface of paper and the direction of Joy is approximately perpendicular to the surface of paper.

3.5. Discussion

Based on the results of our experiments, there are significant rank correlations between Laban features and impressions of basic emotions. These correlations are not always contrary to common knowledge but are not entirely satisfactory. Correlation 1 indicates, for example, that body movement provided with Strong features leaves an impression of Joy. Other elements related to Table Plane Shape should be taken into consideration when the impression of Joy is to be determined. Based on an experimental result, the correlation between Table Plane Shape and the impression of Joy is comparatively close (i.e., 0.67), but it is not evaluated as significant from a statistical viewpoint. As for the diffusion of the experimental result, Correlation 2 indicates that body movement does not look around restlessly when it is Surprised, but this cannot be said as universally acceptable, based on common knowledge. Rather, it will be reasonable to take this as a correlation by appearance produced due to a combination of experimental Dances. The reason why these contradictions or problems arise is probably because the number of Dances adopted for our experiments is only 6. With the addition of other dances, it will be possible to correct the unsatisfactory results of correlation analysis.

For the impression production process based on a factor analysis, a model has successfully been established by the agency of a causation that is characterized by a large factor loading and an efficient orthogonality. This means that Laban features are useful for the description of the impression production process for body movement, and that the validity of the hypothesis for our experiments has been verified.

Once Laban features for body movement of a body movement are established, therefore, it can be said that impressions of body movement are nearly established. Thus, a method can be proposed for controlling the movements for realizing Laban features that will correspond to impressions of a target when it is necessary to control impressions of expressions of a body movement. It is still uncertain, however, whether the correlation established between Laban features obtained this time and the emotional impressions is applicable to a general law. The number of Dances introduced to our experiments is only 6 and only one robot has been adopted as body movement. To make it certain, additional experiments should be conducted in the future.

4. Conclusion

We have shown that sets of Laban features, which quantitatively show the features of body movement, can be practically used when to analyze the production process of impressions on audience about body movement of a body movement, such as a robot. We have offered a guide in how to design and calculate Laban features specifically. To verify the validity of the quantitative analysis, we have conducted a series of experiments with the view of estimating the degrees of basic emotions (joy, anger, grief and pleasure) and proving that there are significant and orthogonal correlations between Laban features and impressions on audience about the emotions.

The results of the experiments show it possible to describe the production process of impressions of body movement mathematically by sets of Laban features.

1) Estimation of impressions by Laban features is yet to be improved with regard to its accuracy. The study on physical features of partial behavior referred to in the introduction in particular can be used for reference to improve the definition of Laban features.

2)The body used in our experiments was a mammal-shaped, in other words, symmetrical body with a head and 2 arms. It is uncertain, however, if Laban theory will applicable to a special, abnormal body. In other words, there should be a theory that can be applied to an uncanny, abnormal perception. If there really is, this theory in combination with Laban theory will be useful for interpreting the perception and understanding of movements.

3) This paper is not yet extended to cover the expression in combination with elements other than body movement. As for the expression elements other than body movement, there are a number of known rules that connect certain expression forms to impressions of them[8]. It is possible, therefore, to study the combination with them. Bodily expressions toward humans with a cooperative use of expression elements will be able to provide a further beneficial psychological effect on humans.

By way of conclusion, we would like to express our designs for the future. The knowledge obtained in this research will make it possible, to estimate and evaluate in advance impressions of the basic emotions produced by arbitrary body movement. This firmly suggests that body movement can autonomously produce body movement and expresses emotions to a human. It will become possible for a machine to analyze movements and also his psychological conditions. Such a machine will serve as an important human-robot communication system.

In addition, if the emotional systems of robots are successfully developed so that the robots can behave like real-animals with proper body expressions, this means that the development of an empathized robot-to-human communication system has reached perfection. The authors are now working on development of this system[13].

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